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National Aeronautics
and Space Administration

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Summary

The main objective of the present investigation was to determine the effect of yttria (Y_2O_3) additions on the modulus of rupture (MOR) and oxidation resistance of pressureless-sintered silicon nitride (Si_3N_4) prepared from milled Si_3N_4 powders contaminated with 5.9 wt% oxygen (11.1 wt% silicon dioxide (SiO_2)). A secondary objective was to determine the effect of substituting alumina (Al_2O_3) for Y_2O_3 in one of the compositions investigated.

Cold-pressed bars were sintered at 1760° C for 4 hours in static nitrogen at 34.5-MPa (5-psi) gage pressure while embedded in a mixture of coarse Si_3N_4 + 5 wt% SiO_2 powders. Ground bars of compositions containing 3.67, 7.22, and 14.0 wt% Y_2O_3 had average MOR's of 460, 515, and 515 MPa at room-temperature and 270, 256, and 227 MPa at 1400° C, respectively. A material with 3.74 wt% Y_2O_3 + 1.69 wt% Al_2O_3 had average MOR's of 452 and 118 MPa at room temperature and 1400° C, respectively. The corresponding MOR's of the best pressureless-sintered Si_3N_4 - Y_2O_3 or Si_3N_4 - Y_2O_3 - Al_2O_3 materials reported in the literature are up to 50 percent higher than these. On the other hand the oxidation resistance of the Si_3N_4 - Y_2O_3 materials from the present investigation was much better than that of the same high-strength materials as well as of hot-pressed Si_3N_4 . At all temperatures investigated (600° to 1400° C) the oxidation resistance of the Si_3N_4 - SiO_2 - Y_2O_3 compositions decreased with increasing Y_2O_3 . Also, although up to ~1200° C the addition of Al_2O_3 did not appear to have much effect on oxidation resistance, it had a very detrimental effect at 1400° C. It is surmised that the lower high-temperature strength and higher oxidation resistance of the Si_3N_4 - SiO_2 - Y_2O_3 materials from the present investigation (as compared with values in the literature) were due to their higher SiO_2 content. None of the compositions investigated showed cracks, blisters, or discolorations, such as reported in the literature for some Si_3N_4 - Y_2O_3 compositions, during oxidation in air in the 600° to ~1000° C range.

Introduction

In a previous NASA investigation (ref. 1) it was shown that high-density Si_3N_4 base ceramics could be

made by pressureless sintering milled Si_3N_4 powders with additions of cerium oxide (CeO_2), magnesium oxide (MgO), or yttrium oxide (Y_2O_3). Although all three additives or their mixtures yielded sintered specimens with about the same maximum percent of theoretical density, it was surmised that Y_2O_3 additions were probably best for optimization of high-temperature properties.

The main objective of the present investigation was to determine the effect of Y_2O_3 additions on the modulus of rupture (MOR) and oxidation resistance of pressureless-sintered Si_3N_4 prepared from milled powders. A secondary objective was to determine the effect of substituting Al_2O_3 for Y_2O_3 in one of the compositions investigated. To attain these objectives, compositions were made from milled Si_3N_4 powders and three different levels of Y_2O_3 . In addition, a fourth composition containing both Y_2O_3 and Al_2O_3 as sintering aids was prepared for comparison. These four compositions were made essentially by the methods of reference 1, which involved the pressureless sintering of prismatic bars made by cold pressing. The sintered and surface-ground bars were tested for MOR and oxidation resistance as functions of temperature.

Materials, Equipment, and Procedure

The materials used in the present investigation were powdered α - Si_3N_4 , Y_2O_3 , and Al_2O_3 . These materials in the "ready for compounding" condition are characterized in table I.

The equipment used in this investigation is described at length in reference 2. Briefly, it consisted of 1.5-liter-capacity, nickel-lined ball mills with nickel shot as the grinding medium and standard laboratory equipment (presses, dies, furnaces, etc.).

The procedures used for the preparation and testing of bars are outlined in the flow diagram of figure 1. Since the procedures used differed only slightly from those used in the work of reference 1, they are described only briefly in this section.

The α - Si_3N_4 was milled with water for 300 hours. During the milling operation the powder picked up nickel from balls and mills. Most of this nickel was removed from the Si_3N_4 -water slurry magnetically. The rest of the nickel was removed from the slurry by leaching with nitric acid (HNO_3), centrifuging to remove most of the water, washing the moist

TABLE I. - CHARACTERIZATION OF RAW MATERIALS

Material	Source; designation	Milling data				Post- milling treatment	Specific surface area of powder, m ² /g	Chemical analysis		
		Mill material	Balls	Milling fluid	Milling time, hr			Oxygen, percent	Carbon, percent	Other elements, ppm unless noted otherwise (spectrographic analyses)
α -Si ₃ N ₄	Kawecki-Berylco Industries; HP	Ni	Ni	Water	300	Leach, centrifuge, wash, cen- trifuge, dry	22.0	5.9	0.14 ^a 0.48	0.3%Al-90Ca-60Cr- 40Cu-0.2%Fe-50Mg- 20Mn-300Ni-Si major- 70Ti-70Zr
Al ₂ O ₃	Union Carbide Corp.; Linde A	--	--	-----	0	-----	14.5	(b)	0.10	80Ca-<10Co-5Cr- <50Cu-20Fe-<5Mn- <20Mo-<100Nb-<5Ni- 50Pb-50Sn-20Ti- <10V-<40W-<100Y- <10Zr
Y ₂ O ₃	Research Chem- icals; 99.9 per- cent pure	--	--	-----	0	-----	69.9	(b)	0.14	50Al-75Ca-<10Co-2Cr- <50Cu-<20Fe-<5Mn- <20Mo-2000Na-<100Nb- 5Ni-<100Pb-<50Sn- 5Ti-<10V-<40W-Y major-<10Zr

^aThis carbon content obtained after mixing 1 hr with 5 wt% silicone oil and 70 wt% ethanol, then heating to 450° C for 1 hr in flowing nitrogen.

^bNot determined.

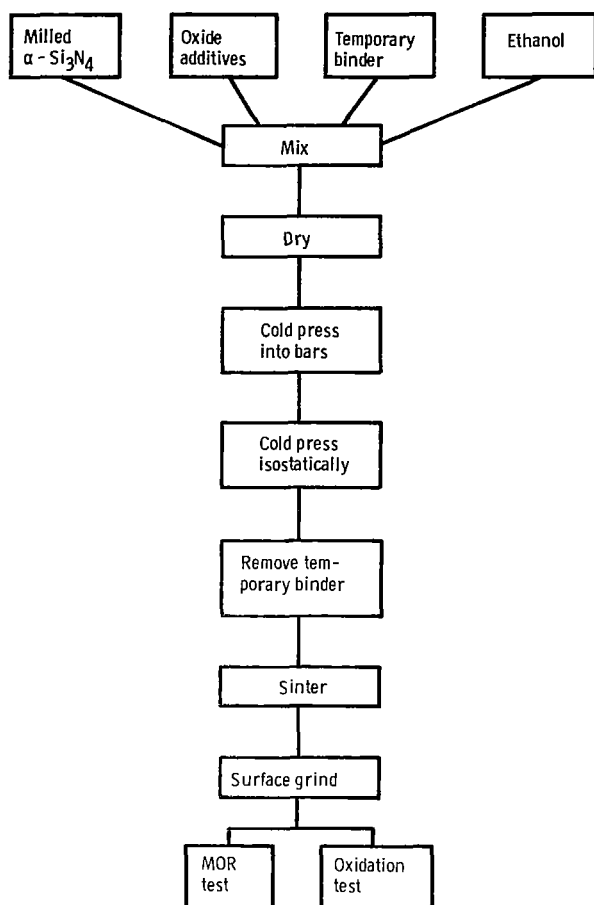


Figure 1. - Flow chart for preparation and testing of Si_3N_4 ceramics.

powder, centrifuging to remove the last traces of dissolved nickel nitrate ($\text{Ni}(\text{NO}_3)_2$) and HNO_3 , drying the moist powder cake, and finally pulverizing the dry powder agglomerates in a Waring Blendor. The milled Si_3N_4 , as well as the as-received and dried Y_2O_3 and Al_2O_3 powders, was analyzed for oxygen and carbon and spectrographically analyzed for trace elements. The specific surface areas of these powders were determined by the BET (Brunauer, Emmett, and Teller) method.

The Y_2O_3 and Al_2O_3 were used in the as-received and dried condition. Because a temporary binder (DC-705 silicone oil) and ethanol were used for specimen preparation, some carbon residue remained in the powder compacts after removal of the binder. This carbon residue was determined by separate experiments, and its value (which was about the same in all the compacted compositions) is shown in table I.

Calculated amounts of the powders characterized in table I were weighed in an analytical balance and mixed with 5 wt% temporary binder and about 70 wt% absolute ethanol. The powders were mixed for 1 hour in a polyethylene bottle with the aid of a few stainless-steel balls. The slurry was dried at about 100°C , and the resulting agglomerates were pulverized in a Waring Blendor. The powder mixtures were shaped into bars approximately 3.81 by 0.92 by 0.47 centimeter by cold pressing at 207 MPa (30 ksi) in a double-acting steel die. These bars were then isostatically cold pressed at 483 MPa (70 ksi). The silicone oil used as temporary binder was removed from the bars by heating them slowly (for ~ 2 hr) in flowing nitrogen to 450°C and holding for 1 hour.

The bars to be sintered were placed in a graphite sintering boat and packed all around with a mixture of -325 mesh $\alpha\text{-Si}_3\text{N}_4$ (Kawecki-Berylco, CP 85) and 5 wt% -325 mesh SiO_2 (Cerac Pure, C-1064). Sintering was carried out at 1760°C for 4 hours in a static nitrogen atmosphere held at 34.5-MPa (5-psi) gage pressure.

The sintered bars were surface ground into 2.54- by 0.635- by 0.318-cm test bars. The bars to be used for MOR tests had their edges beveled 0.12 mm and were tested in the as-ground condition. The bars to be used for oxidation tests were polished on all sides to a mirror finish on a $10\text{-}\mu\text{m}$ diamond lap.

The four-point MOR was determined at various temperatures from room temperature to 1400°C . A silicon carbide fixture having a 1.905-cm (3/4-in.) bottom span and a 0.953-cm (3/8-in.) top span was used for this purpose. The test bar and fixture were heated to the test temperature in air in a silicon carbide muffle furnace mounted on an Instron tensile tester. The bars were bend tested at a crosshead speed of 0.051 cm/min (0.020 in/min).

Oxidation tests in air were carried out at temperatures from 600°C to 1400°C . During these tests the bars were held in an alumina crucible between alumina wedges. To allow access of air, the crucible had two side holes. At various times the bars were cooled, removed from the crucible, and weighed in an analytical balance with microgram sensitivity in order to determine the cumulative weight gains as a function of time.

Results and Discussion

The compositions used in the present investigation are listed in table II. The Si_3N_4 used for making these compositions contained 11.1 wt% SiO_2 , as contrasted with Si_3N_4 with 14.5 wt% SiO_2 used for making some compositions containing the same amounts of Y_2O_3 in reference 1. Therefore, except

TABLE II. - COMPOSITIONS INVESTIGATED

Designation ^a	Composition							
	Si ₃ N ₄		SiO ₂ ^b		Y ₂ O ₃		Al ₂ O ₃	
	wt%	eq%	wt%	eq%	wt%	eq%	wt%	eq%
A	85.64	90.05	10.69	8.75	3.67	1.20	---	---
B	82.48	88.94	10.29	8.64	7.22	2.42	---	---
C	76.48	86.66	9.54	8.42	14.0	4.92	---	---
D ^c	84.07	88.91	10.49	8.63	3.74	1.23	1.69	1.23

^aCompositions A, B, and C are equivalent to Y2, Y4, and Y8, respectively, in ref. 1.

^bCalculated from the oxygen in the milled Si₃N₄ (table I).

^cComposition D is similar to composition B, except that half the Y₂O₃ was replaced with Al₂O₃, on a mole or equivalent percentage basis.

for having somewhat lower SiO₂, compositions A, B, and C, which contain 3.67, 7.22, and 14.0 wt% Y₂O₃ are equivalent to Y2, Y4, and Y8, respectively, in reference 1. In addition, X-ray diffraction analyses showed the same phases (β -Si₃N₄ + Si₂N₂O) in the sintered ground bars. Composition D in table II is similar to composition B except that half the Y₂O₃ was replaced with Al₂O₃ on a mole or equivalent percentage basis. This was done for comparison.

The densities of sintered and ground bars of compositions A, B, C, and D were 97.2, 97.8, 96.0, and 96.8 percent of theoretical, respectively. These theoretical densities were calculated on the basis of the densities of hot-pressed bars, after adjustments for compositional differences and as described in reference 1.

Modulus of Rupture

The four-point MOR's of compositions A, B, and C (table II) as functions of temperature are shown in figure 2. For comparison the four-point-average MOR of GTE Si₃N₄ + 6 wt% Y₂O₃ from reference 3 is also shown in this figure. As the plots in figure 2 show, the room-temperature MOR's of compositions A, B, and C ranged from 416 to 594 MPa, decreasing gradually with increasing temperature to the range of 207 to 312 MPa at 1400° C. The plots also show that

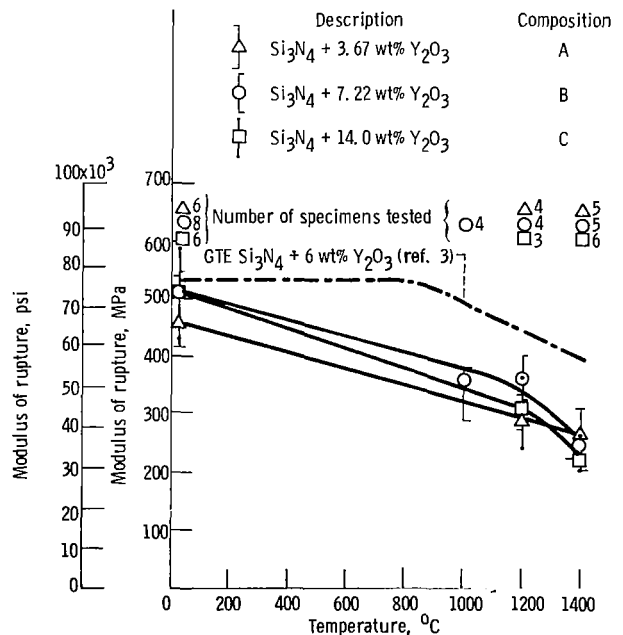


Figure 2 - Effect of temperature and Y₂O₃ additions on four-point modulus of rupture of pressureless-sintered Si₃N₄.

composition A (3.67 wt% Y_2O_3) had an average MOR that was lower at room temperature but slightly higher at 1400° C than the average MOR's of compositions B and C, which had a higher Y_2O_3 content. It is clear from the plots in figure 2 that at 1400° C the MOR decreased with increasing Y_2O_3 content. On the other hand, at room temperature the compositions with the higher Y_2O_3 contents (B and C) were stronger, but it is not clear whether this increased strength was brought about by the higher Y_2O_3 content or by some other unknown factor. Comparison of the plots for compositions B and C with that for the GTE $Si_3N_4 + 6$ wt% Y_2O_3 shows them to have comparable strength at room temperature, but the GTE material was about 50 percent stronger at 1400° C. The higher high-temperature strength of the GTE material was probably due to its lower (~ 5.4 wt%, ref. 3) SiO_2 content and correspondingly smaller amounts of glass phase. Because of its lower SiO_2 content the GTE material was made up of $\beta-Si_3N_4 + Y_2Si_2O_7 + 10Y_2O_3 \cdot 9SiO_2 \cdot Si_3N_4$; and this phase composition, as is shown later, does not have as good oxidation resistance as $\beta-Si_3N_4 + Si_2N_2O$.

In figure 3 are shown plots of the four-point MOR's as functions of temperature for compositions C (7.22 wt% Y_2O_3) and D (3.74 wt% $Y_2O_3 + 1.69$ wt% Al_2O_3). For comparison, plots of the MOR's as functions of temperature for GTE $Si_3N_4 + 6$ wt%

Y_2O_3 and GTE $Si_3N_4 + 6$ wt% $Y_2O_3 + 1.5$ wt% Al_2O_3 are also included in this figure. As the plots show, of the compositions from the present investigation, the one with Al_2O_3 had lower strength at all temperatures than the one without it. Also, although substitution of Al_2O_3 for half the Y_2O_3 moles decreased the strength at room temperature by about 12 percent, it decreased the strength at 1400° C by about 50 percent. On the other hand, of the GTE materials in figure 3, the one with Al_2O_3 was about 22 percent stronger at room temperature and about 50 percent weaker at 1400° C. From these comparisons it is surmised that Al_2O_3 is detrimental to the high-temperature strength of $Si_3N_4-SiO_2-Y_2O_3$ compositions. This holds true whether the Al_2O_3 in material D was regarded as a substitution for Y_2O_3 in composition B or as an addition to the Y_2O_3 in composition A, since the room-temperature strengths of compositions A, B, and D were (within the limits of experimental error) just about the same, as comparison of the plots in figures 2 and 3 shows. On the other hand, it is not clear why Al_2O_3 (whether regarded as an addition to, or substitution for, Y_2O_3) improved the room-temperature strength of the GTE material but not of the materials (either A or B) from the present investigation. This difference in room-temperature strength may be due to

- (1) Different amounts of glass phase
- (2) Different grain sizes (unknown)
- (3) Different impurity contents (the GTE material being much purer)
- (4) Different kinds and amounts of crystalline phases
- (5) Different porosity (96.8 percent of theoretical density for composition D as compared with 100 percent for the GTE material)
- (6) A combination of these factors

Oxidation

The weight increases with time on oxidizing compositions A, B, and C (table II) in air at temperatures from 1000° to 1400° C are plotted in figure 4. For comparison, 1400° C oxidation data for hot-pressed Si_3N_4 (ref. 4) and 1000° C oxidation data for pressureless-sintered GTE $Si_3N_4 + 6$ wt% Y_2O_3 (ref. 3) are also plotted in figure 4. Comparison of the plots from the present investigation shows that, at a given temperature and time at temperature, weight gains increased with increasing Y_2O_3 . From this it is concluded that Y_2O_3 additions are detrimental to oxidation resistance. Yet, even the composition with 14 wt% Y_2O_3 had better 1400° C oxidation resistance than the hot-pressed, commercial Si_3N_4 . Although 1400° C oxidation data

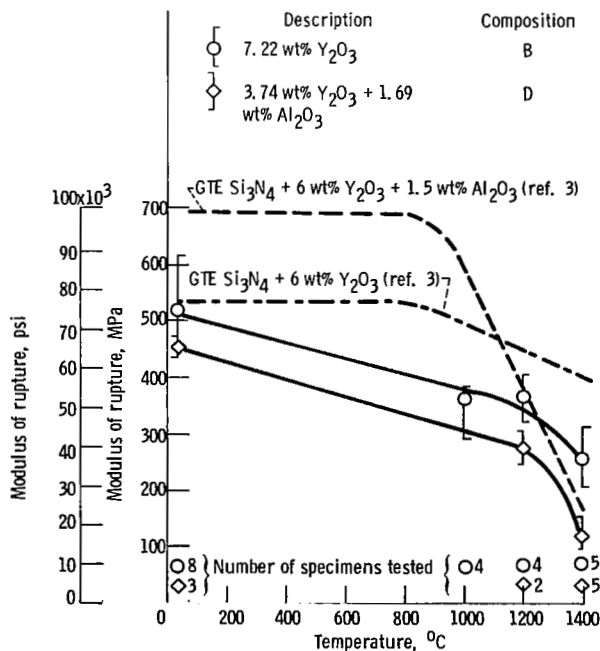


Figure 3. - Effect of temperature and additions of Y_2O_3 or $Y_2O_3 + Al_2O_3$ on four-point modulus of rupture of pressureless-sintered Si_3N_4 .

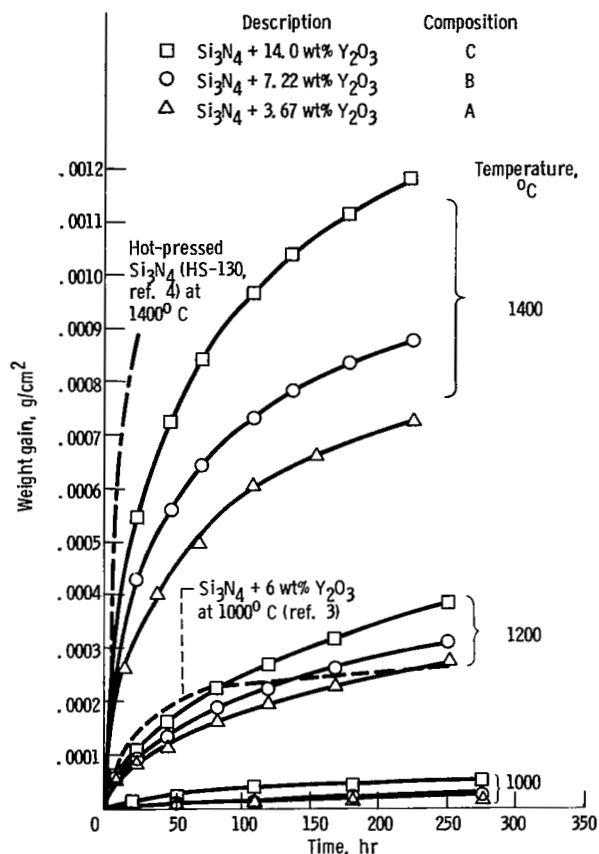


Figure 4. - Weight gain of Si_3N_4 - Y_2O_3 compositions oxidized in air at temperatures indicated.

for the GTE material are not presently available, the 1000° C data from reference 3 presented in figure 4 show that the GTE material had a much higher weight gain than materials from the present investigation with equivalent amounts of Y_2O_3 . The better oxidation resistance of the materials from the present investigation is attributed to their higher SiO_2 content. This SiO_2 content is such (table II) that even with up to 14.0 wt% Y_2O_3 the compositions from the present investigation fall within the Si_3N_4 - $\text{Si}_2\text{N}_2\text{O}$ - $\text{Y}_2\text{Si}_2\text{O}_7$ compatibility triangle of the Si_3N_4 - SiO_2 - Y_2O_3 phase diagram and should, according to reference 5, have better oxidation resistance.

The increase in weight with time on oxidizing composition D (Si_3N_4 + 3.74 wt% Y_2O_3 + 1.69 wt% Al_2O_3) in air at temperatures from 600° to 1400° C is plotted in figure 5. For comparison, the corresponding plots for hot-pressed (HP) Si_3N_4 at 1400° C (ref. 4) and for GTE Si_3N_4 + 4 wt% Y_2O_3 + 2 wt% Al_2O_3 at 1350°, 1200°, and 1000° C (ref. 3) are also plotted in figure 5. Comparison of the plots for composition D in figure 5 with those for

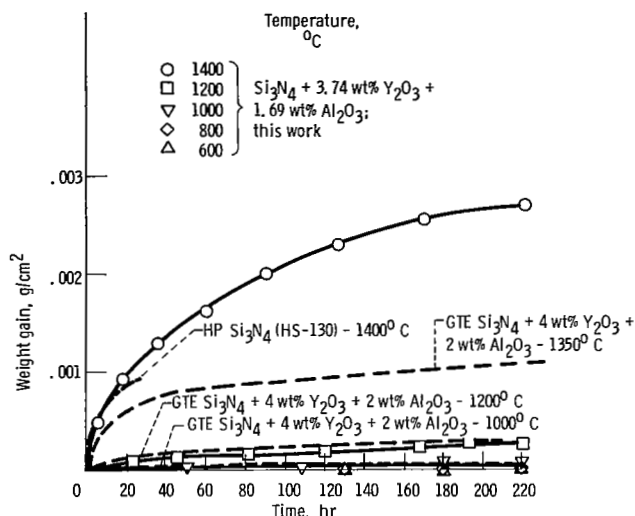


Figure 5. - Comparison of weight gain of Si_3N_4 with 3.74 wt% Y_2O_3 + 1.69 wt% Al_2O_3 oxidized in air at temperatures from 600° to 1400° C to weight gain of other Si_3N_4 materials.

composition B in figure 4 shows that replacement of Y_2O_3 with Al_2O_3 markedly reduced the oxidation resistance of Si_3N_4 + 7.22 wt% Y_2O_3 at 1400° C but that at 1200° and 1000° C the replacement of Y_2O_3 with Al_2O_3 had no significant effect on oxidation. Thus, for instance, after oxidation in air for 220 hours compositions B and D gained in weight 8.7×10^{-4} and 27.2×10^{-4} g/cm² at 1400° C, as compared with 3.02×10^{-4} and 2.47×10^{-4} g/cm² at 1200° C, respectively. Figure 5 also shows that at 1000° and 1200° C the Si_3N_4 - SiO_2 - Y_2O_3 - Al_2O_3 from both the present investigation and reference 3 had about the same oxidation resistance. In addition, considering the weight gain of the GTE material at 1350° C and the pronounced effect of temperature on weight gain in this temperature range, it is surmised that these two materials also have about the same oxidation resistance at 1400° C. This oxidation resistance is comparable to that of hot-pressed Si_3N_4 at 1400° C (ref. 4).

In addition to the results discussed above, compositions A, B, and C were also oxidized in air at 600° and 800° C for up to 400 hours. At 800° C the increases in weight after 400 hours were ≤ 0.00003 g/cm², and at 600° C the increases in weight were not measurable with the equipment used.

The main conclusion derived from these results is that for the materials from the present investigation replacement of Y_2O_3 with Al_2O_3 in Si_3N_4 - SiO_2 base compositions is detrimental to the high-temperature (~1400° C) oxidation resistance. On the other hand, from the data in figure 4, it is surmised that the difference in oxidation resistance at 1000° C between GTE Si_3N_4 + 6 wt% Y_2O_3 and composition B

probably results from differences in the SiO_2 content of the two types of material, as evidenced by the fact that (as shown in ref. 3) preoxidizing this GTE material at 1350°C markedly decreased the subsequent oxidation rate at 1000°C . This effect is reportedly due to an increase in the concentration of surface SiO_2 (ref. 3). The same effect had previously been reported in reference 5 for $\text{Si}_3\text{N}_4\text{-SiO}_2\text{-Y}_2\text{O}_3$ materials with very low SiO_2 content. In this same reference it is reported that certain $\text{Si}_3\text{N}_4\text{-SiO}_2\text{-Y}_2\text{O}_3$ compositions are susceptible to degradation (excessive oxidation and cracking) at relatively low temperatures ($\sim 1000^\circ\text{C}$). This degradation has been attributed to the phases present (ref. 5), to carbon (ref. 6), and to either the tungsten or tungsten carbide picked up on milling (ref. 7). In this context, it may be of interest to note that none of the samples from the present investigation exhibited cracking, spalling, or any other abnormal effect on oxidizing them in air at any temperature from 600° to 1400°C .

Concluding Remarks

From the results of the present investigation it is concluded that increasing amounts of Y_2O_3 decrease the high-temperature strength and the oxidation resistance of $\text{Si}_3\text{N}_4\text{-SiO}_2\text{-Y}_2\text{O}_3$ compositions made from milled Si_3N_4 (contaminated with 11.1 wt% SiO_2) containing from 3.67 to 14.0 wt% Y_2O_3 .

The results of the present investigation when compared with data in the literature suggest that SiO_2 is important to the properties of Si_3N_4 -base ceramics. This comparison shows that increasing the SiO_2 to suitable levels increases oxidation resistance but decreases high-temperature strength. Therefore, within the constraints imposed by composition and particle size on sinterability, it should be possible to obtain Si_3N_4 base materials with either high strength and low oxidation resistance or vice versa by changing the SiO_2 content of the sintered compositions. This SiO_2 content can be varied by varying the surface area (e.g., by varying milling time) of the starting Si_3N_4 powder, by adding SiO_2 , or by removing SiO_2 with carbon additions.

The results of the present investigation also show that, at least for Si_3N_4 with about 6 wt% oxygen (~ 11 wt% SiO_2), Al_2O_3 is detrimental to high-temperature strength and high-temperature oxidation resistance without having much effect on sinterability. Considering the results of Smith et al. with their high-purity Si_3N_4 , it is surmised that the approximately 0.6 wt% Al_2O_3 in the milled Si_3N_4 used in the present investigation may significantly reduce high-temperature strength. Therefore the use of higher purity Si_3N_4 in compositions made by the methods of the present investigation may well provide $\text{Si}_3\text{N}_4\text{-SiO}_2\text{-Y}_2\text{O}_3$ compositions with desirable combinations of high-temperature strength and oxidation resistance.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, May 1, 1981

References

1. Arias, A.: Effects of Oxide Additions and Temperature on Sinterability of Milled Silicon Nitride. NASA TP-1644, 1980.
2. Arias, A.: Pressureless Sintered Sialons with Low Amounts of Sintering Aid. NASA TP-1246, 1978.
3. Smith, Thomas G.; Quackenbush, Carr L.; and Nehring, Vincent: A Review of GTE Sintered Si_3N_4 Structural Ceramics. 5th International Symposium on Automotive Propulsion Systems CONF-800419, Vol. 1, U.S. Dept. of Energy, 1980, pp. 482-499.
4. Tripp, W. C.; and Graham, H. C.: Oxidation of Si_3N_4 in the Range 1300°C to 1500°C . J. Am. Ceram. Soc., vol. 59, no. 9-10, Sept.-Oct. 1976, pp. 399-403.
5. Lange, F. F.; Singhal, S. C.; and Kuznicki, R. C.: Phase Relations and Stability Studies in the $\text{Si}_3\text{N}_4\text{-SiO}_2\text{-Y}_2\text{O}_3$ Pseudoternary System. J. Am. Ceram. Soc., vol. 60, no. 5-6, May-June 1977, pp. 249-252.
6. Knoch, H.; and Gazza, G. E.: Effect of Carbon Impurity on the Thermal Degradation of an $\text{Si}_3\text{N}_4\text{-Y}_2\text{O}_3$ Ceramic. J. Am. Ceram. Soc., vol. 62, no. 11-12, Nov.-Dec. 1979, pp. 634-635.
7. Schuon, S.: Effect of W and WC on the Oxidation Resistance of Yttria-Doped Silicon Nitride. NASA TM-81528, 1980.

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